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RELATION OF VIRUS DISEASES TO POTATO PRODUCTION IN CALIFORNIA[1]

D. R. PORTER[2]

INTRODUCTION

THE ROLE of virus diseases in relation to potato seed production has received attention in nearly every state where seed stock is extensively produced. In California, however, relatively little study has been made. Cultural and environmental conditions in this state are so diverse in the various potato-producing districts that virus study soon becomes so complicated and involved that preventive measures necessarily vary with the locality. Potatoes are extensively produced in southern California, particularly in San Diego, Los Angeles, Riverside, San Bernardino, and Kern counties. In San Diego County the main crop is produced during the winter and early spring, while in the other three counties two crops are often produced from January to November. In northern California, potatoes are extensively grown in certain coastal counties, in the San Joaquin and Sacramento valleys, and to a lesser extent in certain mountainous districts. Average acre yields in excess of 250 sacks are relatively common; thus even a slight loss due to virus infection assumes considerable economic significance.

This report has been prepared primarily for California potato growers. Certain portions, obvious to the reader, are general statements and are applicable regardless of the locality. Original statements, likewise obvious, are the result of investigations conducted in this state since 1929. The text has been arranged so as to first acquaint the reader with the nature of potato virus diseases and then to present the results of studies on field spread and control. The technique of indexing is described in detail in a later section of this paper.

Unless otherwise stated, all work reported herein has been conducted with the variety White Rose, sometimes locally known as Wisconsin Pride.

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VIRUS INFECTION AS A CAUSE OF "RUNNING-OUT"

The nature and effects of virus diseases, only recently recognized in the United States and abroad, have shown that degeneration or "running-out" is not caused by a purely noninfectious physiological disturbance in the potato plant. Instead, the proof of virus infectivity has demonstrated that potato seed stocks may degenerate because of disease, whether in the north or south, in cool or warm climates, with irrigation or with dry-land culture. From virus-infected plants in the seed field, insects or other agents spread the disease to neighboring plants whose tubers in turn harbor it during continued propagation.

ACTUAL CAUSE OF VIRUS DISEASES UNKNOWN

Whereas scab is caused by a bacterium, and wilt by a true fungus, virus diseases have not yet been proved to be caused by any living, visible microörganism; their origin is unknown. The bacteria that induce scab may be seen with the microscope and are too large to pass through a fine porcelain filter, but virus-infected potato juice will usually pass through such a filter and still produce disease. Certain potato viruses are apparently not filterable; that is, the infectious principle apparently will not pass through a porcelain filter. Because, however, such diseases appear very similar to those caused by filterable viruses, they are commonly classified with virus diseases.

If juice from a virus-infected plant is forced into a healthy plant, disease may develop. Such juice diluted with 10 parts or more of water may still be infectious. In many instances if the leaves of a healthy plant are rubbed with fingers that have handled an infected plant, disease will develop. Sometimes the seed-cutting knife carries diseases from infected to healthy tubers. Some spread probably occurs through contact of seed-pieces during planting and through the pickers of the planting machine. Several different species of insects carry the disease from sick to healthy plants; the plant louse or aphid is probably the most common; but certain grasshoppers, leafhoppers, plant bugs, flea beetles, leather jackets, and white flies are also capable of carrying the disease.

PENETRATION IN TUBER

All known virus diseases affecting potatoes are tuber perpetuated; that is, the infected juice passes from the leaves, down the stem, through the stolons, and into the cells of the tuber. Here the virus remains until such tubers are planted. Then, entering the sprouts, it produces characteristic symptoms in the growing plant. There is no known method of killing it within the infected tuber without also killing the buds.

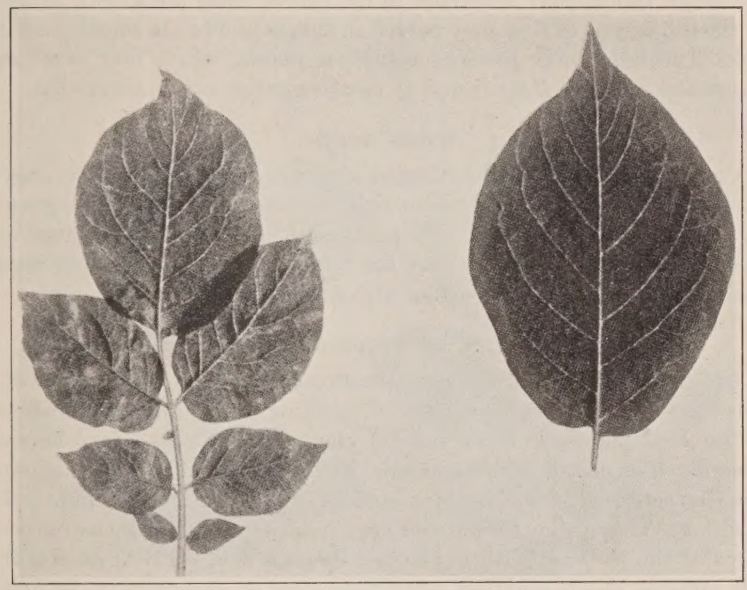

Fig. 1.—Left, mild mosaic; right, healthy leaflet. Green Mountain variety. (Courtesy, United States Department of Agriculture.)

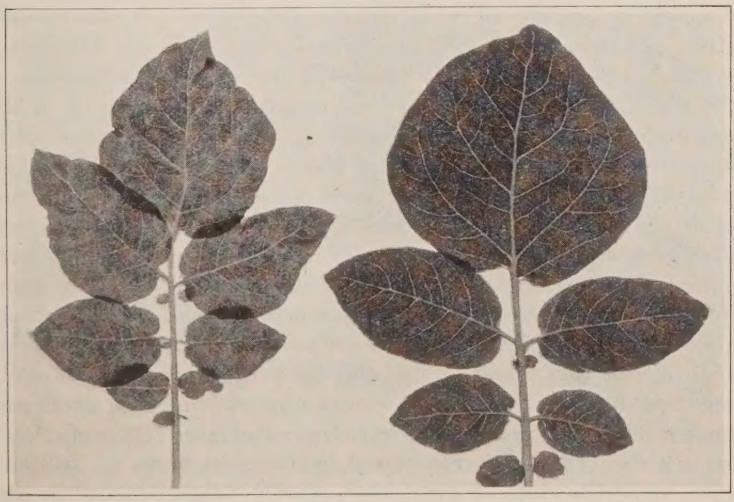

Fig. 2.—Crinkle mosaic, left, compared with a healthy leaf, right. In addition to mottling, the infected leaf is crinkled.

Although viruses may hibernate in the tubers, none are known to live in the soil except as they may persist in tubers allowed to remain in the field. The latter may produce volunteer plants, which may serve as centers of infection if two crops of potatoes are grown in succession.

WEED HOSTS

Certain weeds and such cultivated plants as the tomato, pepper, eggplant, and petunia will harbor some virus diseases, which may be spread by insects from them to healthy potatoes. The relative importance of weed hosts in California as they are related to potatoes has not been investigated except in connection with potato calico.

GROUPS OF VIRUS DISEASES

In general, potato virus diseases naturally fall into two groups, according to the presence or absence of mottling in the individual leaflets of infected plants. For the sake of clarity, these groups are herein designated as mosaic and nonmosaic. The diseases of the mosaic group are characterized primarily by mottling, in which irregular, light yellowish-green or yellowish patches appear in place of the normal green color of the leaflets. With nonmosaic diseases this mottling is absent, but infected plants manifest other symptoms of abnormality, as indicated below. Although as many as 16 potato virus diseases have been described, only 10 have been found in California. The virus diseases of the mosaic group found here to date are mild mosaic, crinkle mosaic, leafrolling mosaic, rugose mosaic, and calico; of the nonmosaic group leafroll, spindle tuber, witch's broom, curly top, and giant hill.

Mild mosaic symptoms (fig. 1) are manifested by mottling in the green leaflet, in which irregular yellowish or light-colored areas alternate with the normal green. Infected plants are slightly dwarfed, and the leaves usually are tender in texture. Sometimes the leaflet margins become slightly ruffled. *Crinkle mosaic* (fig. 2) resembles mild mosaic but, in general, produces more prominent mottled areas and more pronounced crinkling in the leaflets. *Leafrolling mosaic,* as the name implies, is characterized both by foliage mottling and by leaf rolling. Unlike true leafroll, infected leaves are tender, not leathery or tough. *Rugose mosaic* (figs. 3 and 4), probably the most severe and most easily recognized disease of the group, causes numerous mottled areas and intense ruffling of the leaflets and resembles an advanced stage of crinkle mosaic. *Calico* (fig. 5) is recognized by irregular spots of brilliant-yellow, yellowish-white, or gray color, usually unaccompanied by any distortion in the leaflets.[3]

[3] Porter, D. R. The infectious nature of potato calico. Hilgardia 6(9):277–294. Colored plate. 1931.

Potato *leafroll* (figs. 6 and 7) causes upward rolling of the leaflets so that the midrib remains at the middle of the trough thus formed. Infected leaflets become brittle, tough, or even leathery. *Spindle tuber* is

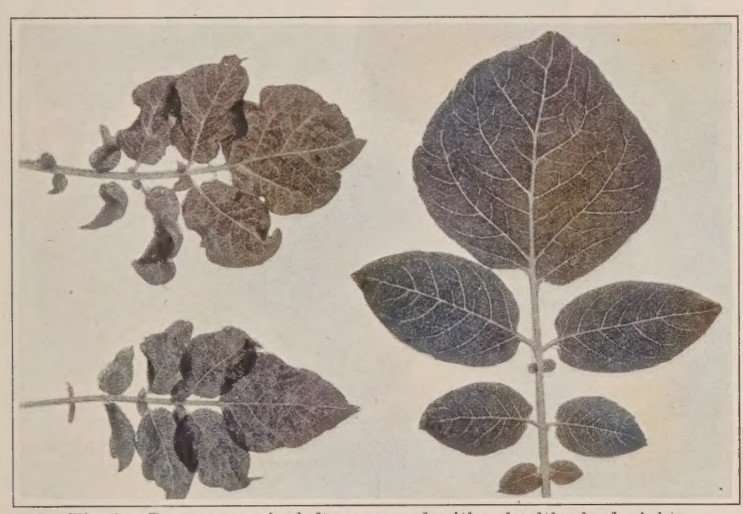

Fig. 3.—Rugose mosaic, left, compared with a healthy leaf, right.

Fig. 4.—The effect of rugose mosaic on growing plants. Green Mountain variety. (Courtesy, United States Department of Agriculture.)

one of the few virus diseases that may be detected in the tuber. Infected potatoes are elongated, often pointed at one or both ends, with more numerous eyes than healthy specimens of the same variety. The plants are usually somewhat darker green than normal and are often erect, rigid, or spindling with an acute angle between the leaves and the main

Fig. 5.—Potato calico. The faded areas are usually lemon yellow and often occupy the entire leaf. High temperatures do not mask symptoms of this disease.

Fig. 6.—Left, healthy plant of Green Mountain variety; right, showing leafroll. (Courtesy, United States Department of Agriculture.)

stem. *Witch's broom*—not often seen in the field in California—is characterized by numerous spindling stems produced from one seed-piece, giving the plant a bushy appearance, with very small rounded leaves. *Giant hill*—rarely encountered—is manifested by rank, coarse growth and by large, irregular tubers. Infected plants appear more frost resistant than healthy ones.

Fig. 7.—Symptoms of potato leafroll (foreground) in the Delta in July, 1930. Symptoms of this virus disease are not masked by high air temperatures.

MASKING OF SYMPTOMS

Symptoms of certain virus diseases, particularly in the mosaic group, are masked when plants are grown at air temperatures above 70° F. On the other hand, spindle-tuber symptoms are more evident at 77° than at 59°. Obviously, masking of symptoms decreases the effectiveness of roguing diseased plants from the seed plot. In California, in fact, it is often the limiting factor in choosing a district for seed production. As potatoes are grown every month of the year in this state, the proper choice of locality or planting date should provide environmental conditions under which comparatively little masking occurs.

With this need in mind, experimental plots have been located in Yolo, San Joaquin, Butte, Kern, Riverside, and Santa Clara counties. Frequent observations have also been made in Los Angeles, San Diego,

Monterey, Alameda, Contra Costa, Marin, and Humboldt counties. In many of these districts, two crops are commonly produced per season, giving ample opportunity to determine, under field conditions, the frequency of symptom masking. In general, masking is rare near the coast and at relatively high elevations. In these localities, though midday air temperatures may often exceed 70° F, with lower temperatures from late afternoon until the following forenoon, the tendency for masking is not great. Much of the previous investigation of the weather, in this connection, has been made under controlled conditions with relatively little fluctuation from day to night. Thus, the time factor in relation to frequency of masking may assume considerable importance. The effects of sunlight intensity have not been thoroughly investigated, being hard to separate from those of high air temperature. In interior California, with intense sunlight from early morning until late afternoon, careful study has shown the individual plants infected with mild or crinkle mosaic, though manifesting mottling at or soon after daylight, often appear healthy by 10:00 A.M. Such plants may again show mottling for several mornings; but eventually, with continued high air temperatures, even the early morning symptoms seem masked. With spindle tuber, leafroll, witch's broom, and calico, high air temperatures apparently favor rather than conceal disease symptoms.

VARIATION OF SYMPTOMS

In order to determine more accurately the relation of environment to masking, the following experimental procedure was used for three seasons: Large, previously indexed tubers found infected with mild mosaic, crinkle mosaic, rugose mosaic, calico, leafroll, and leafrolling mosaic were cut into four seed-pieces. These pieces, identified by number, were planted in four localities: always at Davis (Yolo County), Stockton (San Joaquin County), Santa Clara (Santa Clara County), and either Shafter (Kern County) or Temecula (Riverside County). Thus the performance of sister seed-pieces could be ascertained under varying environmental and cultural conditions. Obviously, with planting in interior California possible from February to July, the problem was extremely complicated. Hence, this procedure was repeated at Davis and Stockton, during three years, by planting diseased sister seed-pieces during early March, early May, and late June. Symptoms were recorded at Davis weekly, at Stockton and Santa Clara approximately every 15 days, and at Shafter, Riverside, and Temecula twice during the growing season.

Because of the relatively infrequent opportunity to study the plants, the data secured by comparing sister seed-piece progenies planted in

the outlying plots are not tabulated here. According to certain general conclusions, however, at Stockton, Shafter, and Riverside, seed-pieces known to be infected with the mild mosaic virus usually produce apparently healthy plants; at least, the symptoms are not sufficiently obvious to make roguing effective. In like manner, seed-pieces infected with crinkle mosaic often produce plants free of mottling, though the crinkling symptoms are sometimes evident. With leafrolling and rugose mosaic, mottling likewise is often masked; but the leafrolling and

Fig. 8.—Muslin-covered cages used to protect potato plants from virus infection by insects.

rugose symptoms are seldom disguised, so that it is possible to detect and rogue infected plants. Calico and leafroll are easily detected even under conditions of extreme heat.

At Santa Clara, symptoms of all the diseases mentioned above were evident during three seasons' observations. Occasionally, mild mosaic was partially masked; but the other diseases were easily detected, making roguing rapid and effective.

The results at Davis agree, in general, with those at Stockton. As previously indicated, sister seed-pieces from diseased tubers were planted in adjoining rows during early March, early May, and late June. The resulting plants could therefore be studied when grown early, medium early, and late. Individual plants were often observed three times during the day in order to determine whether symptoms evident soon after daylight later became masked with rising air temperature and increased sunlight intensity. In some instances sister seed-pieces were also planted within muslin-covered cages (fig. 8) in order to determine the effect of decreased sunlight intensity.

Conclusions from the Davis trials are as follows: In early-planted stock from tubers infected with mild mosaic, crinkle mosaic, leafrolling mosaic, rugose mosaic, calico, and leafroll, characteristic symptoms are

usually—but not always—evident during March, April, and early May. With increasing air temperature in May, symptoms of mild mosaic often disappear; the mottling of crinkle and leafrolling mosaic often becomes masked while the crinkling or leafrolling symptoms persist. Calico, leafroll, and rugose mosaic are manifest until the plants begin to mature. With similar stock planted in early May, symptoms of all diseases are usually evident until the first of June, when masking occurs with mild, crinkle, and leafrolling mosaic. In early June, night tempera-

TABLE 1

EFFECT OF CONTINUED INDEXING ON PREVALENCE OF VIRUS DISEASES

Classification of indexed plants	1930	1931	1932	1933
	per cent	*per cent*	*per cent*	*per cent*
Healthy	28.3	60.1	83.4	86.4
Mild mosaic	15.3	7.8	8.2	4.0
Crinkle mosaic	18.8	11.3	4.3	3.7
Rugose mosaic	3.6	0.6	0.2	0.2
Leafroll	5.9	4.7	2.6	1.3
Spindling sprout*	28.1	15.5	5.3	4.4

* The nature of the spindling sprout virus, as indicated here, was not definitely determined. Tubers thus infected may produce weak plants under greenhouse conditions and are often responsible for an uneven stand in the field.

tures are usually low enough and last long enough so that mottling may be detected for four or five hours after sunrise; but these symptoms become masked before noon. As with the very early planting, calico and leafroll are apparent until the plants approach maturity. In the late-planted plots, it is almost impossible to detect mottling characteristic of the mosaic diseases except calico; but crinkling, leafrolling, and rugosity are often evident. Leafroll and calico-infected plants manifest symptoms continually.

EXTENT OF INFECTION DURING CONTINUED INDEXING

During the past five years many California-grown potato seed stocks have been indexed at Davis in order to secure definite information on the extent of virus infection. In this regard, it seemed advisable to measure the cumulative effects of indexing the same stocks over a period of years and to determine whether the resulting seed plots were adequately isolated from other sources of infection.

The procedure was as follows: Stocks were indexed, and the healthy tubers planted in increase plots in various localities. From the crop thus produced, a representative collection was indexed during the succeeding winter. The healthy tubers were retained and planted in the seed plot, and again samples were collected for indexing. Thus the practica-

bility of indexing could be determined, and the rate of decrease of virus diseases measured.

The summarized data covering the actual indexing results are presented in table 1. Both crinkle and mild mosaic were commonly found in 1930, but by 1933 each had declined to approximately 4 per cent. Leafroll decreased from 5.9 to 1.3 per cent, and rugose mosaic was prac-

Fig. 9.—Virus-disease transmission plot at Santa Clara in 1931. Tubers infected with rugose mosaic planted in the middle row. Other rows planted with healthy seed stock. See table 2 for rate of spread.

tically eliminated by 1933. The percentage of healthy plants rose from 28.3 in 1930 to 86.4 in 1933.

After four years of indexing one might expect the percentage of healthy plants to exceed 86.4; but all the seed plots were located in interior California, and some were not well isolated from commercial fields. The results show clearly that continued indexing tends to eliminate virus diseases from the seed stocks even in localities where masking of symptoms makes field roguing uncertain and where field spread is extensive.

RATE OF SPREAD IN THE FIELD

In connection with studies on symptom expression, considerable attention has been devoted to the rate, extent, and distance of spread in various localities. Conceivably, as insects are the chief sources of field spread, localities might be found where normal spread is sufficiently slow to permit production of relatively virus-free seed stock, provided

adequate roguing could be practiced. Critical study of the insect population in potato districts has not been made; but apparently, with the advent of high air temperatures during June, July, and August, activity and prevalence of aphids decrease. It seemed worth while, accordingly, to measure the spread in stocks planted on different dates from March to July. This work was done with early-planted stock at Davis, Stockton, and Santa Clara, with additional stock planted medium early at Davis and Stockton, and with late-planted stock only at Davis.

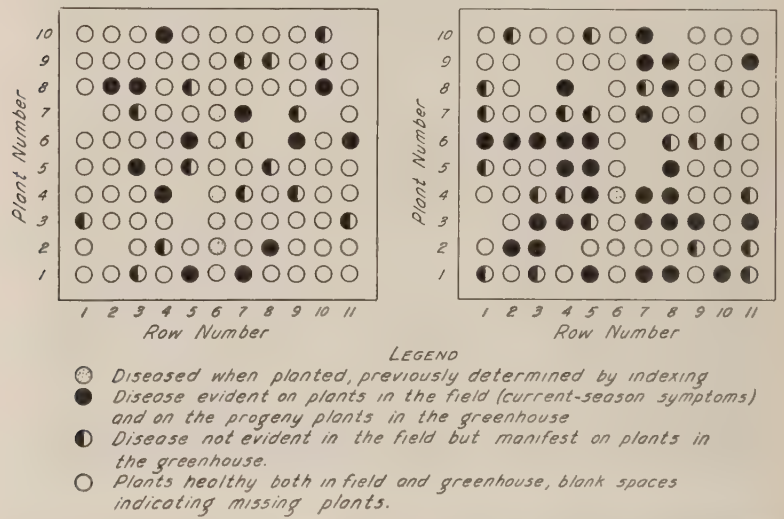

Fig. 10.—Field spread of rugose mosaic (left) and of leafroll (right) at Santa Clara in 1931, indicating both current-season and actual spread as determined by indexing each hill in the greenhouse.

The method was as follows: During the winter, greenhouse indexing provided healthy[4] seed stock as well as stock infected with mild, crinkle, leafrolling, and rugose mosaic, with calico, and with leafroll. Eleven rows of ten hills each in the field constituted a plot (fig. 9), the middle row being planted with stock infected with a single virus, and five rows on either side with healthy stock. Each plot was isolated. After emergence, frequent readings indicated the extent of visible current-season spread. Two weeks after emergence, all hills were thinned to one stalk. At maturity the originally healthy hills were dug separately, and the tubers numbered with India ink in order to preserve their location in the field. When the normal dormant period had passed, two tubers from each hill were indexed in the greenhouse; and the resulting plants fur-

[4] In this bulletin healthy stock means tubers which, when indexed, produced plants apparently free of any known virus disease.

nished complete information on the actual field spread during the growing season. The results in representative plots are shown in figures 10 to 13, inclusive, covering data secured at Davis, Stockton, and Santa Clara.

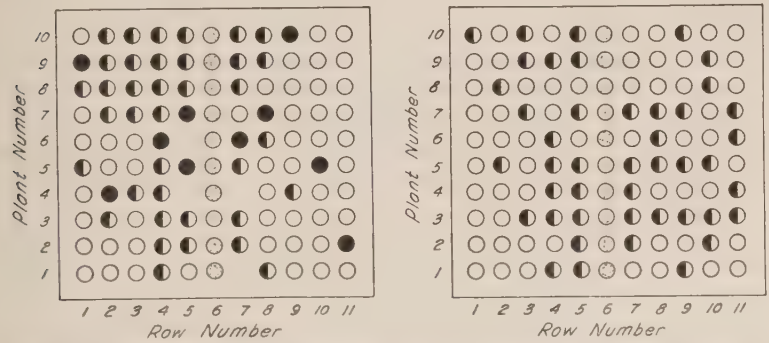

Fig. 11.—Field spread of rugose mosaic (left) and leafrolling mosaic (right) in the Delta in 1930, determined by field and greenhouse readings. See figure 10 for legend.

Field spread of rugose mosaic, leafroll, mild mosaic, and leafrolling mosaic was measured at Santa Clara in 1931 and 1932. Its extent in representative plots in 1931 is shown in figure 10 for rugose mosaic and

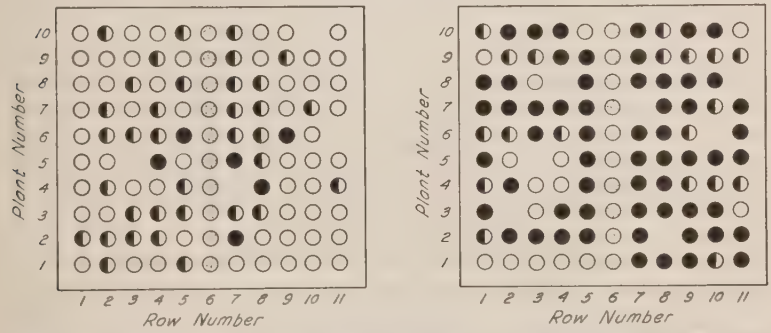

Fig. 12.—Field spread of mild mosaic (left) and of leafroll (right) in the Delta in 1930, as determined by field and greenhouse readings. See figure 10 for legend.

leafroll. Current-season symptoms of rugose mosaic were evident on 13 per cent of the plants, whereas actual spread, determined by greenhouse tests, was 29 per cent. During 1932, current-season and perpetuation symptoms were manifested, respectively, on 9 and 22 per cent of the plants. Evidently, normal field spread at Santa Clara was less rapid than in the Delta (fig. 11).

Leafroll at Santa Clara in 1931 (fig. 10) spread more extensively then rugose mosaic, with 28 per cent current-season and 49 per cent perpetuation symptoms. In 1932, the figures were 21 and 36 per cent, respectively. Both diseases spread less at Santa Clara than in the Delta (fig. 11).

In 1930 only 9 per cent rugose mosaic (current-season symptoms) was evident in the Delta (fig. 11); but progeny tests in the greenhouse showed the actual field spread to be 47 per cent.

Although no current-season symptoms of leafrolling mosaic were evident (fig. 11), greenhouse tests indicated 44 per cent infection in the ten rows, with approximately equal spread in both directions of the diseased row.

Likewise, current-season symptoms of mild mosaic were rarely evident in the Delta in 1930 (fig. 12), with only 2 per cent visible infection in the plot. In greenhouse tests, however, 41 per cent of the plants manifested mild mosaic symptoms, with no significant difference in extent of spread to the north or south of the diseased row.

The results with leafroll spread are in direct contrast to those secured with the three mosaic diseases (fig. 12). Current-season symptoms were evident on 58 per cent of the plants, and perpetuation symptoms indicated an actual spread of 77 per cent. Symptoms of leafroll are not masked by the relatively higher air temperature.

Similar trials at Davis in 1931 resulted in approximately the same relative spread as in the Delta in 1930 (fig. 13). The extent of infection was as follows: current-season spread for rugose mosaic 8 and for leafroll 32 per cent; actual spread, rugose mosaic 45 and leafroll 72 per cent. Field spread of mild and leafrolling mosaic was measured at Davis in 1931, with the following results: current-season symptoms for mild mosaic, 4 per cent, and for leafrolling mosaic, 2 per cent; actual spread of mild mosaic 49 per cent and of leafrolling mosaic 52 per cent.

FIELD SPREAD IN RELATION TO YIELD OF PROGENY

Growers often inquire regarding the extent of isolation necessary for their seed plot; that is, they appreciate the possibility of field spread from diseased stock but do not know how far insects will carry the viruses. It is probably safe to assume that they will carry it as far as they migrate. The migration of aphids, probably the chief insect vectors, is governed by air temperature and wind velocity. The winged forms of aphids are commonly seen in the Delta, in Kern County, and in the coastal districts; and with high wind velocity they probably move a considerable distance. Probably, if healthy stock is planted where potatoes are not intensively grown, the number of viruliferous insects is

relatively low; but under intensive culture, as in the Delta, the Shafter-Wasco district, and some sections of southern California, aphid transmission of virus diseases to the seed plot may assume considerable importance.

The investigations of natural field spread, described above, indicated that, in general, infection was more prevalent in the rows adjacent to the diseased stock than in those removed by five rows (figs. 10, 11, 12, and 13), regardless of the location of the plot. This evidence led to a critical study of the yielding power of stock produced in the five rows

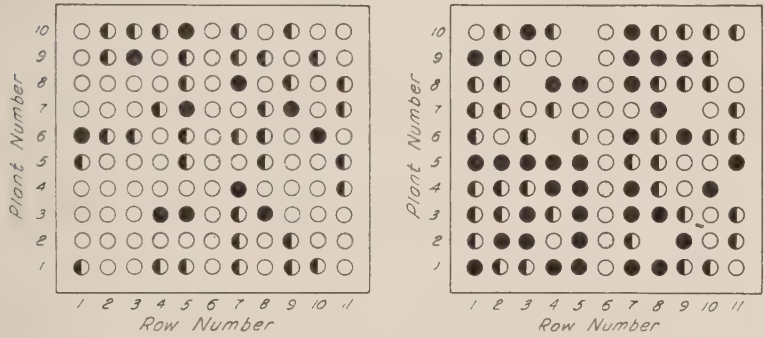

Fig. 13.—Field spread of rugose mosaic (left) and leafroll (right) at Davis in 1931, as determined by field and greenhouse readings. See figure 10 for legend.

on either side of the diseased specimens, in order to determine the extent of correlation between yielding power and proximity to diseased stock. The following investigations were conducted from 1930 to 1932, inclusive, at Davis, Stockton, and Santa Clara.

Both healthy and diseased stocks were isolated by indexing in the greenhouse. Five healthy rows were planted on either side of a row infected with one of the following: mild mosaic, crinkle mosaic, rugose mosaic, or leafroll. Planting dates varied with the season and locality, but all plots may be considered as "early planted." As 20 sets were planted per row, each plot contained 200 healthy plants. Each hill was thinned to one stalk. Three tubers from each of the 200 hills were saved for planting the following season. Yields were determined at Davis in adequately replicated plots comparing the seed produced by the ten rows. The results (table 2) indicate certain effects of virus infection in relation to yield reduction as well as a general tendency for more infection in rows adjacent to diseased stock than in rows farther away.

TYPE OF DISEASE IN RELATION TO RATE OF SPREAD

Regardless of the locality, the results further show that actual field spread was invariably more extensive for both rugos mosaic and leafroll than for either crinkle or mild mosaic. Current-season symptoms of both leafroll and rugose mosaic were commonly observed, while mild

TABLE 2

INFLUENCE OF THE AMOUNT OF INFECTION ON YIELD

Disease	Distance, in feet, from diseased stock in seed plot	Actual per cent infection	Computed yield of the progeny in 100-pound sacks per acre							
			From Davis plot			From Stockton plot		From Santa Clara plot		Average
			1930	1931	1932	1930	1931	1931	1932	
Mild mosaic	3	33 3	139 8	148.9	161 4	129 2	126 8	188 3	181 5	153 7
	6	30.2	154 6	160 3	157 3	136 1	124.8	186 0	173 6	156 1
	9	28.6	141 2	158 1	179 3	151 4	160 6	202 8	206 4	171 4
	12	26.3	187 3	149 7	203.4	180 6	178.8	209 2	219 2	189 8
	15	21.1	166 0	170 3	191 8	174 3	162 8	228.3	221 5	186.3
Average		*29.1*	*157.8*	*157.4*	*178 6*	*154 3*	*150.7*	*202.9*	*200.4*	
Crinkle mosaic	3	56.8	126 1	151.6	149 3	108 8	121 3	181 5	189 0	146 8
	6	61.1	134 8	146 8	146 2	106.3	124 4	211 5	194 0	152 0
	9	46.7	121.1	173.9	166 4	133 8	118.7	198 3	209.9	160 3
	12	34.1	140 7	171.2	173 8	149 2	146 1	191 7	204.0	168 1
	15	32.8	162.8	166.3	161.2	154.2	146 3	201 3	197.9	170 0
Average		*47.1*	*137.1*	*161.9*	*159.4*	*130.4*	*131 3*	*196.9*	*198.9*	
Rugose mosaic	3	73.6	76.3	89 3	94.8	63.9	60 8	92.6	97.4	86.3
	6	76.1	70.8	91.4	90.6	66.1	58.3	94.3	91.3	80.4
	9	61.2	84 6	84.9	93.6	60 8	71.4	82.9	90.1	81.2
	12	47.8	89.2	112.6	99.1	84.6	86.3	126.8	126.6	103.6
	15	32.2	91.3	141.1	126.3	79.8	83.5	146.1	148.6	118.1
Average		*59.6*	*82.4*	*103.8*	*101.5*	*71.1*	*78.1*	*108.5*	*110.8*	
Leafroll	3	78.3	89.4	100.8	129.1	70.1	82 2	133.4	141 2	106 6
	6	80.2	86.2	128 3	123 6	70.4	94 1	162 3	180 6	121.3
	9	66.1	100.8	121 9	146.1	81.4	87.8	150 6	147.2	119.4
	12	60.3	98.6	148.6	139.5	80.2	99.6	134.6	136.1	119.6
	15	51.1	114.4	141 1	151.1	89.2	101.3	139.6	149 5	126 6
Average		*69.5*	*97.9*	*138.1*	*137.9*	*78.5*	*93.0*	*144.1*	*150.9*	

and crinkle-mosaic symptoms were frequently masked, becoming evident only when the stock was indexed. The relative merits of the three localities, as regards the production of healthy seed, are likewise apparent, no matter what the particular disease to which healthy stock was exposed. Seed produced at Santa Clara invariably yielded more the following year than did seed produced either at Davis or at Stockton. These data do not justify the conclusion that exceptionally disease-free seed may be promiscuously produced at Santa Clara, for the figures on

yields indicate that field spread did occur. The data in figure 10 indicate, furthermore, that insect vectors served as carriers. Aphids were present in the plots in all three localities, but for some reason, apparently, were most active at Stockton. As already noted, all these plots were planted before April 15, and the plants were exposed to aphid infestation for several weeks before the advent of prolonged high air temperatures.

REDUCING RATE OF SPREAD IN THE FIELD

The data and discussion presented thus far show that, from the standpoint of normal field spread over a period of three years, none of the localities mentioned has proved adapted to the production of disease-free stock in fields planted early. For several years, potentially high-yielding seed has been produced in the Delta by delaying planting until midsummer. Though the crop has not been free of virus diseases, seed thus secured, when planted relatively early the following spring, has yielded remarkably well in comparison with similar stock resulting from early (March and April) planting.

There are probably at least two reasons why stock planted late in interior California (June 15 to July 1) is potentially high yielding. First, it matures in October or November, so that the seed tubers are relatively free of shriveling and sprouting by planting time the following year. Early-planted stock, on the other hand, matures in July or August, is exposed to high air temperatures during late summer unless placed in cold storage, and is often severely shriveled and low in vitality by planting time. Seed-pieces from such tubers often produce sprouts in excess of the normal number but of low vitality. A second reason, probably more important than the first, is that aphids are seldom active on plants growing during high summer temperatures prevalent in July, August, and September, but are extremely active and numerous during March, April, and May. Since these insects are the chief vectors of potato viruses, their scarcity naturally contributes to the absence of severe virus infection in late-planted stock.

TIME OF PLANTING IN RELATION TO VIRUS PREVALENCE IN THE PROGENY

Experimental evidence indicates that high-yielding seed stock may be produced in interior California by delaying the planting of healthy stock until early June. The investigations were conducted at Davis, where virus diseases spread at practically the same rate as at Stockton.

During the winter, potatoes large enough to cut into three seed-pieces were indexed in the greenhouse, providing healthy tubers and tubers infected with certain virus diseases. Three rows were planted in the

field at intervals of approximately six weeks, the actual dates varying with the season. In each row, one seed-piece of each of 100 tubers (50 healthy and 50 diseased) was planted in the same relative position on the three different dates. Thus, each healthy plant was exposed to infection from identically diseased plants, regardless of planting date. At maturity, the tubers from each originally healthy plant were harvested separately, marked with India ink, and stored at 3½° to 5° C until they

TABLE 3

TIME OF PLANTING IN RELATION TO FIELD SPREAD, AT DAVIS

Year	Time of planting	Per cent visibly infected plants in field	Greenhouse data on progeny			Field data on performance of progeny		
			Average plant height, inches	Average stem diameter, cm	Per cent infected plants	Per cent stand	Per cent visibly infected plants	Average plant yield, pounds*
1930	March 21	18.6	14.1	0.48	87.1	80.0	43.1	0.97
1930	April 1	21.3	13.8	0.47	80.6	74.6	40.6	0.95
1930	May 6	2.9	19.1	0.76	7.3	100.0	9.3	2.48
1931	March 25	26.6	16.8	0.55	94.3	95.3	48.3	1.20
1931	April 20	11.3	21.3	0.63	31.8	100.0	18.9	2.48
1931	June 5	1.1	26.9	1.09	3.6	100.0	4.8	2.84
1932	March 20	31.6	13.3	0.54	98.0	81.6	39.7	1.31
1932	May 2	8.3	20.1	0.51	41.1	100.0	20.2	3.12
1932	June 25	0.0	29.3	0.95	5.9	100.0	7.4	4.01
Averages for 3 years	Early	28.8	14.7	0.52	91.5	83.3	41.1	1.16
	Medium	11.8	18.4	0.54	54.3	89.0	28.3	2.25
	Late	1.9	25.1	0.93	5.9	100.0	6.0	3.11

* Plants spaced 18 inches apart in the row and 36 inches between rows.

had passed through the dormant period and could be indexed. Results indicated the extent of field spread in relation to planting date. Three tubers from each originally healthy hill were reserved for planting the following season, care being taken to plant an equal number of seed-pieces from each hill.

Data covering these trials for three years are presented in table 3, showing exact planting dates, extent of visible field spread, greenhouse data on actual field spread, plant size, and field data on the next season's crop in terms of percentage stand, extent of infection, and yield. The 1930 trials show that both current-season symptoms and actual spread decreased when planting was delayed until May 6. The actual spread in the early (March 21) planting was 87.1 per cent; in the late (May 6) planting, only 7.3 per cent. The emergence for the two plantings was 80.0 per cent and 100.0 per cent, respectively; the average yield, 0.97 and 2.48 pounds per plant. Similar results were secured in 1931, with the

late planting delayed until June 5. Current-season spread was reduced from 26.6 to 1.1 per cent; actual spread, from 94.3 to 3.6 per cent. Average plant yield for the early and late plantings were, respectively, 1.20 and 2.84 pounds, an increase of 137 per cent. In 1932, the late planting was further delayed until June 25. As a result, no visible current-season infection occurred, and actual spread dropped from 98.0 to 5.9 per cent. Plant yield increased from 1.31 pounds (early planting) to 4.01 (late planting). The average for the three dates clearly indicates that stock planted late produces higher-quality seed than stock planted

TABLE 4

DATE OF PLANTING IN RELATION TO VIRUS-DISEASE SPREAD AT DAVIS

Planting date*	Per cent virus diseases evident in field†			Per cent virus diseases determined by indexing in the greenhouse			Average yield of progeny in sacks per acre‡		
	1930	1931	1932	1930	1931	1932	1930	1931	1932
Early	21.9	18.6	11.6	91.3	84.3	96.5	96.1	84.4	102.0
Medium	29.2	3.1	2.0	100.0	20.6	14.5	103.2	176.8	192.6
Late	4.1	0.0	0.0	8.3	2.8	3.1	176.9	246.5	308.2

* Planting dates were as follows: In 1930, March 21, April 1, and May 6; in 1931, March 25, April 20, and June 5; in 1932, March 20, May 2, and June 25.

† Indicating current-season spread from diseased plants.

‡ Computed from data on yield per plant.

early. There is a progressive decrease in both visible and actual spread, and a progressive increase in plant size, in per cent stand, and in average plant yield of the next generation.

The beneficial effects of late planting are further shown by table 4. In these trials, healthy stock was planted in the field near stock infected with several virus diseases, on the dates indicated. No particular attention was paid to the exact location of either the healthy or the diseased seed-pieces, thus approximating the conditions under which the average seed grower would work. Seed was saved only from the originally healthy plants, one tuber from each hill was indexed in the greenhouse, and the remaining tubers were massed for yield tests the following year.

In 1930 late planting reduced the percentage of actual field spread from 91.3 to 8.3, in 1931 from 84.3 to 2.8, and in 1932 from 96.5 to 3.1. With this reduction in virus infection, yields increased from 96.1 to 176.9 sacks per acre in 1930, from 84.4 to 246.5 in 1931, and from 102.0 to 308.2 in 1932.

INSECT CONTROL IN RELATION TO SPREAD IN THE SEED-PLOT

Because insects are recognized as the chief vectors of potato viruses, an attempt was made to check the field spread of disease by using nicotine sulfate to decrease aphid infestation. Two 11-row plots were planted

as described for the other field-spread trials, the middle row with known diseased stock and five rows on either side with healthy stock. Sister seed-pieces were used for the two plots, and each hill was thinned to one stalk. One plot was dusted once each week, and one was not.

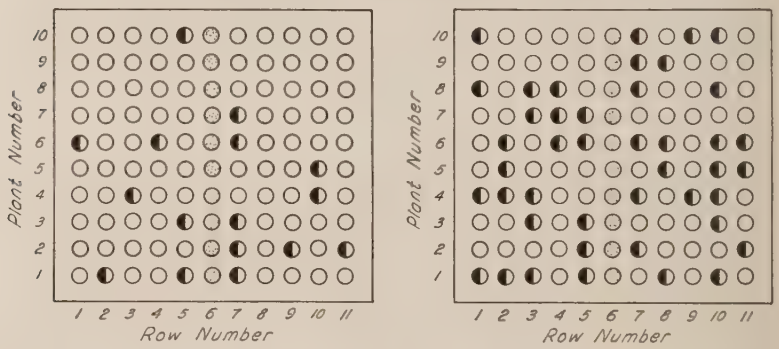

Fig. 14.—Field spread of mild mosaic at Davis in 1930 in dusted plot (left) and check plot (right) as indicated by greenhouse readings on plant progeny. See figure 10 for legend.

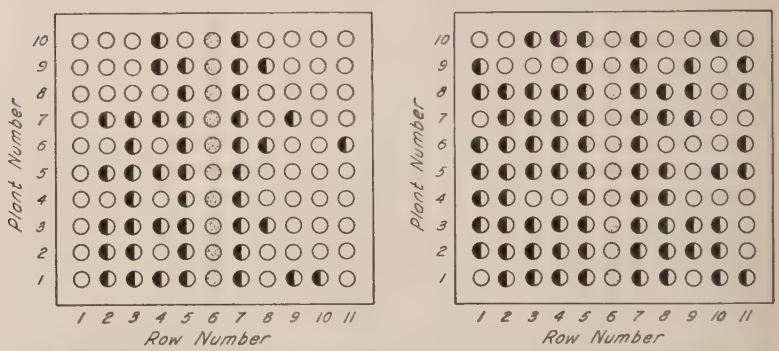

Fig. 15.—Field spread of crinkle mosaic at Davis in 1930 in dusted plot (left) and check plot (right) as indicated by greenhouse readings on plant progeny. See figure 10 for legend.

The 1930 results with mild mosaic are presented in figure 14, with crinkle mosaic in figure 15, and with leafroll and rugose mosaic in table 5. Dusting decreased the percentage of mild mosaic infection from 43 to 16, crinkle mosaic from 73 to 43, leafroll from 65 to 57, and rugose mosaic from 52 to 36. Evidently, though frequent dust applications tended to decrease actual field spread, such reduction was far from adequate from the standpoint of the seed grower. A similar test was made in 1931 with almost identical results.

SEED-PLOT LOCATION AND ISOLATION AS THEY AFFECT YIELD OF PROGENY

The practical value of the investigations described thus far can best be measured by comparing the *yielding* ability of seed stocks produced with different conditions of isolation, at different planting dates, and in different localities. Such tests have been made annually since 1930 (fig. 16).

Fig. 16.—Seed-test plot at Davis, 1933. Middle row, *a*, planted with stock resulting from early planting at Davis in 1932; row *b* with late-planted stock of 1932; and row *c* with stock grown at Santa Clara in 1932. See table 6 for comparative yields.

In 1930, healthy tubers were cut into three seed-pieces, which were planted early in seed plots at Davis, Stockton, and Santa Clara, respectively. With individual tubers divided in this fashion, the seed produced in these plots would be genetically identical, and any difference in comparative yielding power of the progeny would be caused mainly by virus infection. No attempt was made to isolate these plots from other potatoes, the idea being to determine how locality affects seed quality with respect to disease.

The results of this trial (table 6) indicate that healthy seed stock at Davis and Stockton degenerated rapidly when exposed to field infection and planted early.

Growers generally recognize that if potatoes are planted early (March and April) in the Delta, the resulting crop is of inferior value as seed stock because of extensive virus infection, either from occasional infected potato plants or from certain weed hosts. In general, the Delta growers rarely attempt to produce seed with the early crop. Further-

more, they rarely attempt to isolate their seed fields from the fields where table stock is being produced.

To test the practicability of seed-plot isolation, even though the crop was planted early, a preliminary trial was conducted in the Delta in

TABLE 5

FIELD SPREAD OF LEAFROLL AND RUGOSE MOSAIC AT DAVIS IN 1930, COMPARING DUSTED WITH NONDUSTED PLOTS

Row No.	Per cent leafroll		Per cent rugose mosaic	
	Dusted	Check	Dusted	Check
1	30	50	30	40
2	20	40	70	70
3	60	40	20	100
4	50	100	20	80
5	90	100	60	50
6*	100	100	100	100
7	90	80	50	80
8	80	90	30	40
9	60	70	20	40
10	40	50	40	0
11	50	30	20	20

* Row 6 in each of the test plots for leafroll and rugose mosaic was planted with tubers infected with the respective viruses.

1931. Healthy tubers were planted as tuber-units on Ryer Island in April, in a plot separated by at least two miles from other potatoes and in a district where potatoes had not been grown recently. A few diseased units were rogued in May and the resulting crop was planted in a seed-

TABLE 6

SPREAD OF DISEASE IN VARIOUS SEED PLOTS AS MEASURED BY YIELD AND EXTENT OF DISEASE IN THE PROGENY

Location of seed plot, 1931	Per cent stand in progeny, 1932			Per cent visibly diseased, 1932			Computed yield in sacks per acre, 1932	Per cent disease in progeny as shown by indexing, 1933
	April 22	April 28	May 5	April 22	April 28	May 5		
Santa Clara	93.3	96.6	97.3	5.5	8.1	8.1	237.1	14.5
Stockton	77.7	86.7	87.7	30.1	33.6	33.6	123.6	83.4
Davis	79.2	87.2	89.5	14.3	21.3	21.3	131.5	71.1

test plot at Stockton in 1932. Seed from Minnesota and Oregon was planted in comparison with this Ryer Island seed, in four replications.

The relative yields in sacks per acre were as follows: Minnesota, 390; Ryer Island, 334; Oregon, 313. It is recognized that these relative yields mean little as the three lots of seed were not of the same origin, but it

seems significant that the Ryer Island stock yielded at the rate of 334 sacks per acre. There are probably three reasons for this high yield: the stock had been indexed and only healthy tubers planted; the seed plot, though planted early in the Delta, was well isolated from other potatoes; and field roguing served to eliminate certain diseased hill-units overlooked during indexing. Furthermore, the Ryer Island plot was planted

TABLE 7

Progeny Yield of Potato Seed Stocks Grown under Various Conditions of Isolation, Location, and Planting Date

Lot	Seed-plot history during 1932	Computed yield in 100-pound sacks per acre, 1933	
		At Stockton	At Davis
A	Indexed in greenhouse during the winter of 1931-32. Increased in an isolated, tuber-unit seed plot at San Jose in 1932. Not rogued. Planted May 15, 1932	389	287
B	Identical with lot A but increased on Ryer Island in the Delta. Not rogued. Planted April 10, 1932	368	275
C	Field-run stock produced at Temecula, Riverside County. Not indexed and not rogued	332	244
D	Identical with lot A but planted on July 8, 1932, at Davis. Diseased plants rogued	402	308
E	Identical with lot A but planted on May 11, 1932. Diseased plants rogued	294	192
F	Late-planted in the Delta in 1932 from Minnesota seed stock of 1931. Not indexed and not rogued. Planted June 15, 1932	313	264
G	Field-run stock grown in Humboldt County in 1932. Not indexed and not rogued	312	242
H	Stock grown in Minnesota in 1932. Average of 15 lots	359	

in April, the crop was dug early in August, and the tubers were kept in cold storage until the following April, so that eight months elapsed between digging in 1931 and planting in 1932. The vitality of such stock may have been lowered during this long storage period; yet the yield was profitable—334 sacks per acre.

After certain benefits of late planting and rate of field spread by localities had been determined, the test summarized in table 7 was conducted in 1933 with seed produced in 1932. Seven lots of seed were used, designated by letters from A to H, inclusive. The seed represented by lots A, B, D, and E was from the same source; but each lot was handled differently in 1932 as regards planting date and locality. The effects of

isolation may be measured by comparing lots A and B with E, as all were planted early in 1932—lot A at Santa Clara, lot B on Ryer Island, and lot E at Davis. The effects of late planting are measured by comparing lot D with E, both having been planted at Davis—in July and May, respectively. Lot C was produced in Riverside County by a grower whose entire crop was well isolated from other potatoes; lot F in the Delta as a late-planted crop in 1932, having been grown in Minnesota in 1931; lot G as selected stock in Humboldt County; lot H as the average of 15 lots produced in Minnesota in 1932. The yield comparisons were made both at Davis and Stockton in plots where each lot was planted in four replications.

Whereas the average yield of 15 different lots produced in Minnesota in 1932 (lot H) was 359 sacks per acre, lots A, B, and D all yielded in excess of this amount. Whether the increased yield of these three lots is significant is not known, but at least they all produced as well as Minnesota-grown stock. The actual yields seem less important than the demonstration that potentially high-yielding seed may be produced in interior California, both at Davis and in the Delta, provided proper attention is paid to indexing, tuber-unit planting, field roguing, planting date, and seed-plot isolation. Whether such precautions can be made a part of the California potato growers' operations is for each individual to decide.

Lot D yielded at the rate of 402 sacks per acre, an increase of 108 over lot E. These two lots, grown at Davis, were identical; that is, healthy tubers were halved, one half being planted on May 11 (lot E) and the other half on July 8 (lot D) in tuber units. Both lots were field-rogued. In this instance degeneration proceeded at the rate of 26.6 per cent in one season. This comparison adequately demonstrates what may be accomplished by delayed planting of healthy seed stock in the Sacramento and lower San Joaquin valleys of California.

Yields of these eight lots at Davis were much lower than at Stockton; but the results further strengthen those previously discussed, the relative order being practically the same. The late-planted Davis stock yielded highest, while the early-planted degenerated from 308 to 192 sacks per acre.

VARIETAL RESISTANCE

As already pointed out, loss from virus diseases can be prevented only by the intelligent and diligent application of several control measures. It is necessary to index seed tubers, to plant as tuber-units, to rogue carefully and frequently, and to isolate the seed plot from diseased stocks. These practices, being strictly *temporary* in effect must be employed every year.

Permanent prevention of virus diseases of certain plants other than potatoes by using resistant strains and varieties has become possible within the past fifteen years. Resistance has been found in certain well-established varieties or has been developed by crossing an undesirable resistant variety with susceptible commercial varieties. Sugar cane mosaic, bean mosaic, sugar-beet curly top, and spinach mosaic (blight) are virus diseases that may be thus controlled. The Irish Cobbler and Spaulding No. 4 (Synonym Rose No. 4) potato varieties have long been known to resist mild mosaic.

TABLE 8

Yield Comparisons of Katahdin and White Rose Varieties at Stockton in 1932

Variety	Location of seed plot and season of Planting in 1931	Yield per acre in 100-pound sacks			
		Planted April 8 1932	Planted April 25 1932	Planted May 12 1932	Average
Katahdin	Maine	449	332	419	397
Katahdin	California, planted late	462	407	353	407
Katahdin	California, planted early	432	344	277	351
White Rose	Minnesota, average of 9 lots	472	405	346	393
White Rose	California, planted late	401	379	290	357

More recently, the United States Department of Agriculture has developed, by breeding, two varieties resistant to mild mosaic.[5] These, Katahdin and Chippewa, have been placed with various experiment stations for trial in order to determine their regional and environmental adaptation. Katahdin was tested in California in 1931, 1932, and 1933; Chippewa only in 1933. Both produced vigorous plants, attractive tubers, and high yields. In general, their tuber type does not meet market demands in California, where a "long, white" tuber is preferred. The Katahdin tuber is described as short-elliptical to roundish; the Chippewa tuber as elliptical to oblong. The former matures late; the latter medium late. Conceivably, Chippewa might be substituted for Triumph in the Colma district or for British Queen and White Rose as a winter crop in San Diego County.

Katahdin was planted in a test plot[6] in the Delta in 1932 in comparison with White Rose and Burbank, with the results shown in table 8. Three lots of Katahdin seed yielded as well as White Rose, or better.

Comparative yields of Katahdin and healthy White Rose at Davis have been approximately equal during three years.

[5] Clarke, C. F., *et al.* The Katahdin and Chippewa potatoes. U. S. Dept. Agr. Cir. 276:1–8. 1933.

[6] This test was conducted by Weyl-Zuckerman at Stockton. The author is indebted to Mr. H. G. Zuckerman for the data used in table 8.

To date no comparative yield records of Chippewa and healthy White Rose are available; but trials conducted in 1933 show that the former more nearly approaches the "long, white" type than does Katahdin.

Fig. 17.—Equipment for indexing potato tubers. The tubers are marked with India ink; and after each tuber is cut, the knife is dipped in formaldehyde and then washed in water. As a substitute for formaldehyde, the knife may be dipped in wood alcohol and flamed.

Although mild mosaic is not the most serious potato virus disease in California and although Katahdin and Chippewa are not known to resist virus diseases other than mild mosaic, this demonstration indicates that future work may result in the development of varieties resistant to

such diseases as leafroll, crinkle mosaic, and rugose mosaic, which are much more malignant than mild mosaic in California. Some foreign varieties are resistant to leafroll, and perhaps by crossing, this resistance may be combined with the tuber type and quality of American varieties.

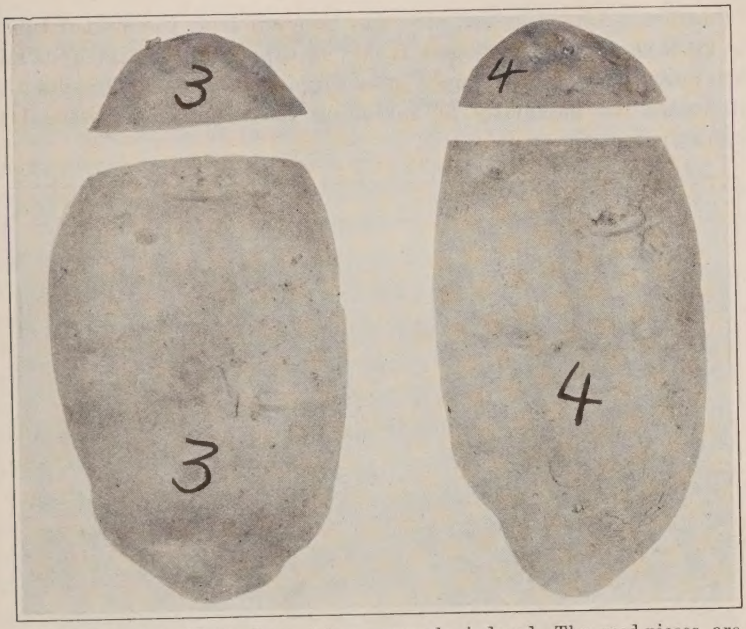

Fig. 18.—Two White Rose tubers properly indexed. The seed-pieces are planted in the greenhouse or early in the field. The tubers are stored until index readings are made on the plants produced by the seed-pieces.

TECHNIQUE OF TUBER-INDEXING

In tuber-indexing, one seed-piece of a single tuber is tested before the planting season in the field. The practice assumes that the virus, if present, is well distributed within the tissues, so that all plants produced by a tuber will manifest either health or disease. Thus diseased tubers may be detected, and only healthy stock used in the seed plot.

Tuber-indexing requires a minimum of equipment (fig. 17). Tubers are numbered consecutively with waterproof India ink that dries rapidly. Each is marked in two places (fig. 18), so that both the seed-piece and the remainder bear the same number. The mother tubers are induced to form callus in moist atmosphere and may then be stored at low temperatures. The seed-pieces are immediately planted either in 4 or 5-inch clay pots or in a bed in the greenhouse. If the latter is not available they may be grown in a hotbed or sash-covered cold frame. Indexing

should be started at least six weeks before the planting season. The growing plants should be examined about 10 days after emergence and at weekly intervals thereafter. All diseased plants are recorded, their mother tubers discarded, and only healthy specimens planted in the seed plot.

Caution.—After the seed-piece has been cut from the mother tuber, the knife should be disinfected. It may be dipped in formaldehyde and then rinsed in water, or flamed after dipping in alcohol. This practice eliminates the possibility of spreading the virus from diseased to healthy tubers.

Fig. 19.—A tuber-unit seed plot planted at Wasco with tuber-indexed stock in 1930. The computed yield per acre was 237 sacks, and only 9 of the 357 units were rogued.

PROCEDURE IN ESTABLISHING TUBER-UNIT SEED PLOTS

As many seed-pieces as possible are cut from each healthy indexed tuber, and all those from one "mother" are planted in succession in the row. This grouping constitutes the tuber-unit. The units may be separated in the field either by wooden stakes or by a space of 3 or 4 feet between units. This precaution facilitates roguing, all the seed-pieces from a tuber being adjacent in the row. Invariably a few diseased tubers are planted in the seed plot because some plants produced during indexing were apparently healthy, but actually diseased. If even one seed-piece produces a diseased plant, all plants in its unit should be rogued and removed from the field, since they may be symptomless carriers.

Seed plots planted with tuber-indexed stocks have been grown in several localities from Butte to Riverside County. A typical plot, located at Wasco in 1930 is shown in figure 19. The foundation stock was indexed during the winter of 1929–30, when only 357 or 70.7 per cent of the tubers were healthy. These healthy tubers were planted as units in the field at Wasco in February, 1930. During the growing season, only nine units were rogued because of suspicious virus infection.

TIME OF INDEXING

Although, as stated, tuber-indexing may advantageously be practiced in the greenhouse, such facilities are not always necessary. Instead of a greenhouse, growers may use a cold frame covered with sash, or a hotbed in which fresh stable manure or electricity serves as a source of heat. The area of cold-frame or hotbed space necessary for 1,000 seed-pieces is approximately 240 square feet, for a planting distance of 6 inches both between rows and between plants in the row. If necessary, the planting distance may be reduced to only 4 inches both ways; then 1,000 seed-pieces would require approximately 120 square feet, or a hotbed 20×6 feet. The sash or muslin covering could be used to protect the young plants from low temperatures and to keep the soil warm during germination.

Even without hotbed or cold-frame facilities, indexing may often be accomplished in the open field 4 to 6 weeks before the main planting, after danger of frost has passed and before the rush season begins. Usually, in the Shafter-Wasco district, the index plot can be planted in the open field in early January; in Riverside County in February or early March; and in the Delta region between February 15 and April 1. In these localities, as a matter of fact, the index planting could be postponed until the main planting season, because the seed plots must be planted much later for reasons discussed elsewhere in this paper.

SUMMARY

Virus diseases in California may reduce the yield of table stock 25 per cent. Though reductions of such magnitude are relatively uncommon in the more important potato districts, virus-disease infection may nevertheless represent the difference between profit and loss.

Potato *seed* production in California should be attempted only by growers of considerable experience with crop-culture and disease-control measures. The quality of seed stock is mainly determined by the health of the plants that produce the seed tubers. The value of seed stock should not be judged solely on the basis of the physical appearance of the tubers.

Tuber-indexing serves to locate healthy tubers for planting in the seed plot. It may be accomplished in the greenhouse, hotbed, cold frame, or, in some districts, in the open field early in the spring.

Climatic, geographic, environmental, and physical conditions in California are so diverse that general recommendations regarding potato-seed production cannot be made except with reservation. These variables, either alone or in combination, serve to limit those districts where high-quality seed may be produced. Each region usually has its disadvantages, whether they be virus-disease prevalence and spread, seed dormancy, varietal adaptability, soil type, climate, or growing and marketing facilities.

In many districts, masking of symptoms of certain virus diseases is common. For this reason, effective roguing of diseased plants is usually impractical.

In every district where careful study has been made, virus diseases normally spread rapidly during one growing season unless the seed plot is well isolated or planting is delayed until June 15 or later. Diseased plants serve as sources of infection, but because of symptom masking cannot always be detected.

Although field spread may be reduced by applying insecticides to the foliage of growing plants, such protection is not sufficiently beneficial to justify the practice.

In general, if plants are grown during periods of extreme heat, common to interior California from June to September, comparatively little field spread of virus diseases occurs. Because of symptom masking, previously mentioned, seed used to produce such a crop must be practically free of the mosaic diseases. Plants affected with nonmosaic diseases may usually be detected even during conditions of high air temperature and should be rogued from the seed plot.

Potentially high-yielding seed may be produced in the California Delta by planting early—that is, in March or April. Tuber-indexed seed must be used, however, and the seed plot must be well isolated from all sources of virus infection. The results of the Ryer Island trials verify this statement. Whether early planting and consequent isolation are practical remains for the individual grower to decide.

In general, late-planted (June and July) seed produces potentially high-yielding stock in interior California. Such seed, however, must be relatively free of virus infection, because adequate roguing is impossible after June 1.

The importance of seed-plot isolation has been demonstrated at Davis, at Santa Clara, on Ryer Island, and in southern California.

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